The Higgs Portal

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The Higgs and the hidden sector

SM — H — Hidden Sector
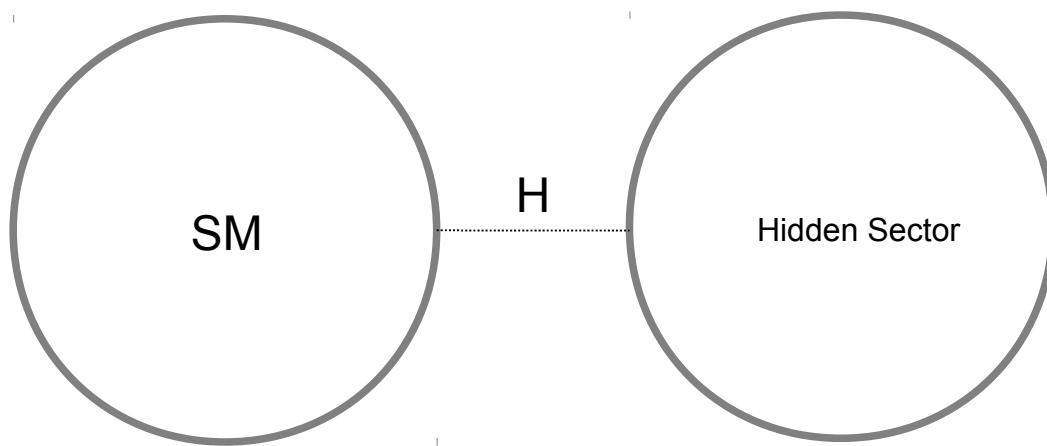
<u>Lowest order operators</u> ("Higgs Portal") :

$$\overline{H}H\, S^2 \quad + \quad \dots \qquad \qquad \text{(scalar)}$$

$$\overline{H}H\, V_\mu V^\mu \; + \quad \dots \qquad \qquad \text{(vector)}$$

$$\overline{H}H\, \overline{\chi} \chi \, / \, \Lambda \; + \quad \dots \qquad \qquad \text{(fermion)}$$

"Portal" due to Patt,Wilczek'06   (earlier : Silveira,Zee'85; Shabinger,Wells'05;...)

Silveira, Zee '85
Veltman, Yndurain '89
...

Special role of the Higgs :

$|H|^2$ = the only gauge and Lorentz-inv. dim-2 operator

$$L = a\,|H|^2\,S^2 + b\,|H|^2\,S$$

(S = "hidden" scalar)

b=0 (S has hidden charge):

$$L = a\,|H|^2\,S^2$$

"S" is stable and couples weakly to SM   -->   DARK MATTER (?)

Constraints on Higgs-singlet mixing :

H_1 = 125 GeV Higgs ; H_2 = extra Higgs   ; θ = mixing angle

Falkowski, Gross, OL '05
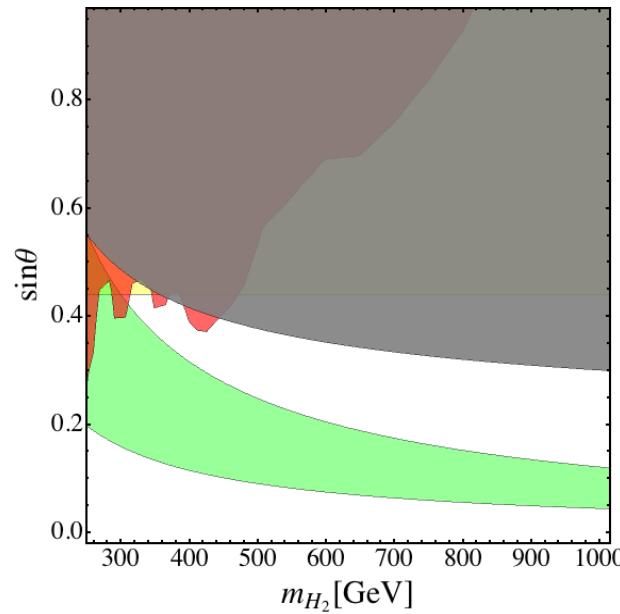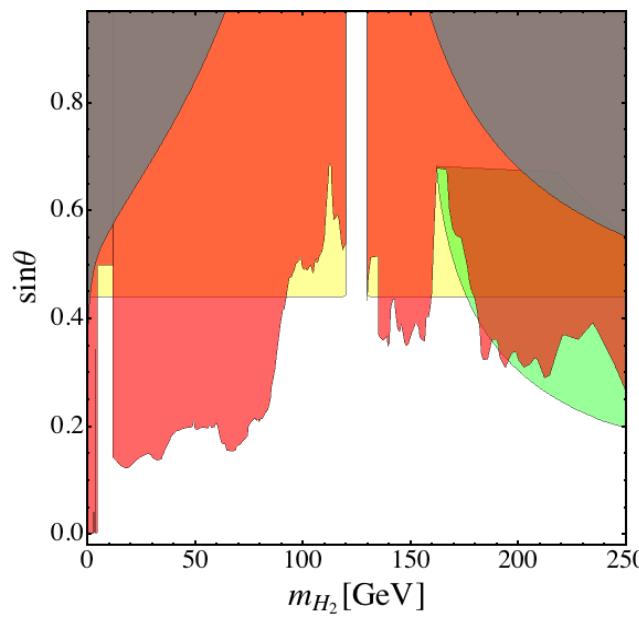
Grey = EW precision data , Yellow = LHC Higgs couplings , Reddish = B-physics, LEP, LHC

Green (optional) = Higgs potential stability/perturbativity up to M_{Pl}

Vector Higgs portal:

$$L = a \, |H|^2 \, V_\mu V^\mu \; + \; b \, (\overline{H} i D_\mu H \, V^\mu + \text{ h.c.})$$

(V_μ = "hidden" vector)

$b = 0$ ($V^\mu \leftrightarrow -V^\mu$ symmetry):

$$L = a \, |H|^2 \, V_\mu V^\mu$$

V^μ = DM (?)

Higgs mechanism in the hidden sector :

$$L = -1/4\ F_{\mu\nu}\ F^{\mu\nu} + D_{\mu}S^*\ D^{\mu}S - V(S) + \lambda/4\ H^*H\ S^*S$$

$$S \longrightarrow VEV$$

$H^*H\ V_{\mu}V^{\mu}$ vertex

(Z_2 parity)
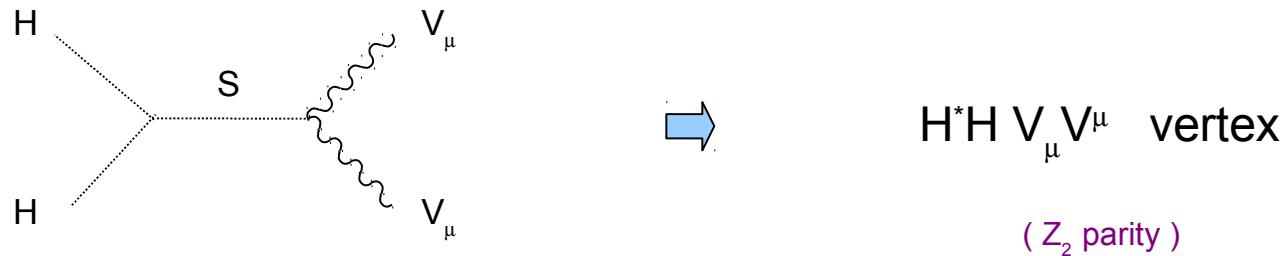
gauge invariance (+ minimal field content)

$$\Downarrow$$
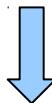
Z_2

Non-abelian case:

V^2

V^1

V^3

$\Rightarrow$ Z_2 odd
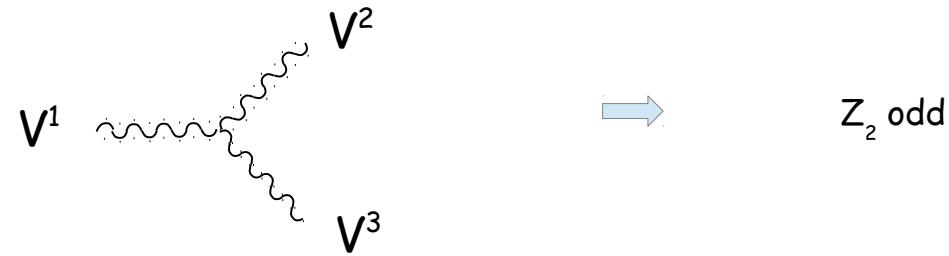
But there are 2 Z_2's:

$$V^{1,2} \longrightarrow - V^{1,2} \quad , \quad V^3 \longrightarrow V^3$$

$$V^{1,3} \longrightarrow - V^{1,3} \quad , \quad V^2 \longrightarrow V^2$$

$\Rightarrow$ V^a = stable

Non-abelian Higgs portal:

$$L = a |H|^2 \; V^a_\mu V^{a\mu}$$

Important processes :

annihilation

DM-nucleon scattering

invisible Higgs decay

V_μ

SM

SM

H

$< \sigma v >$

V_μ

V_μ

V_μ

H

q

q

σ_{S-P}^{SI}

H

V_μ

V_μ

Γ_H^{inv}
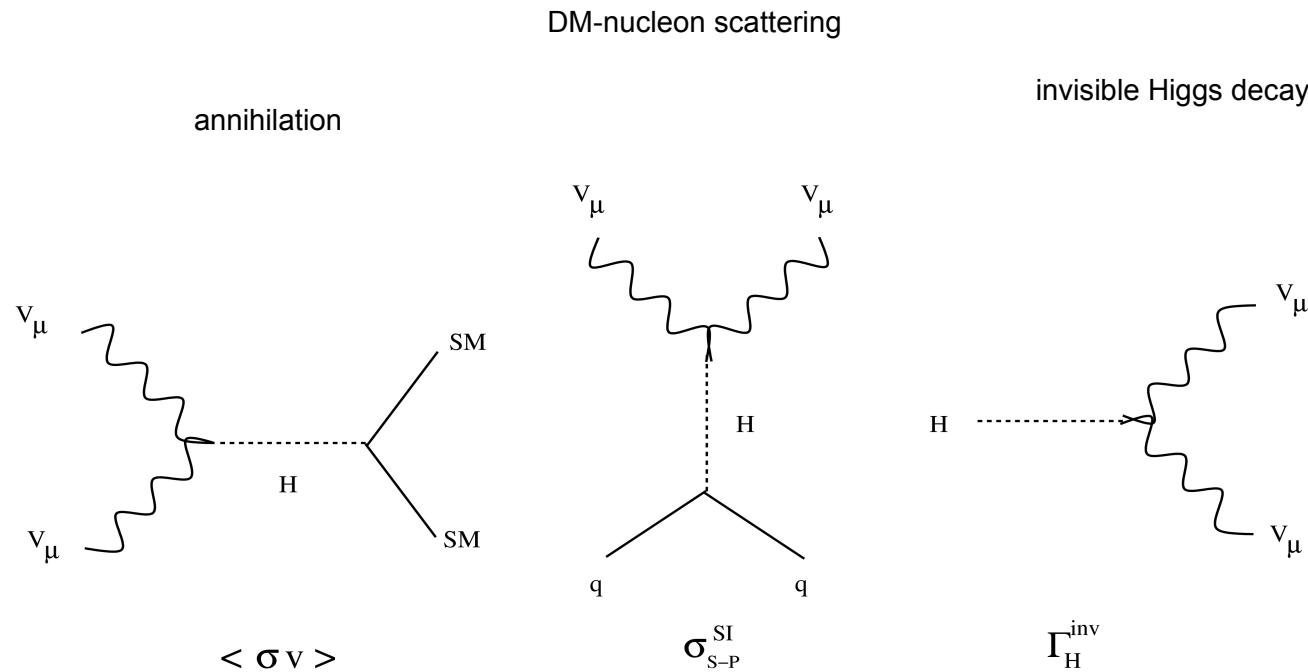
⟹ DM direct detection with $\sigma \sim 10^{-8} - 10^{-10}$ pb

Probing gauge fields of the hidden sector

SM $\quad$ H $\quad$ G_N
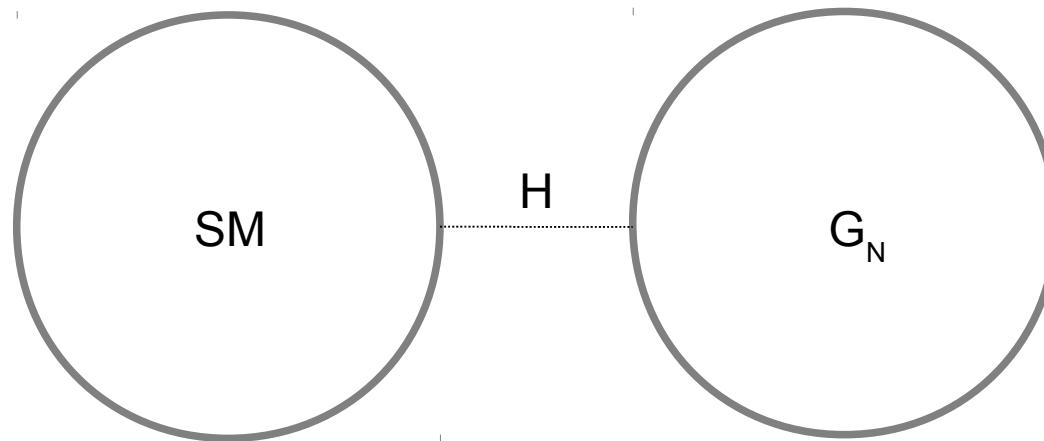
$V \sim \overline{H}H\,\overline{S}S$ $\quad\Longrightarrow\quad$ H-S mixing $\quad\Longrightarrow\quad$ **h couples to G_N**

Monojet + missing E_T :
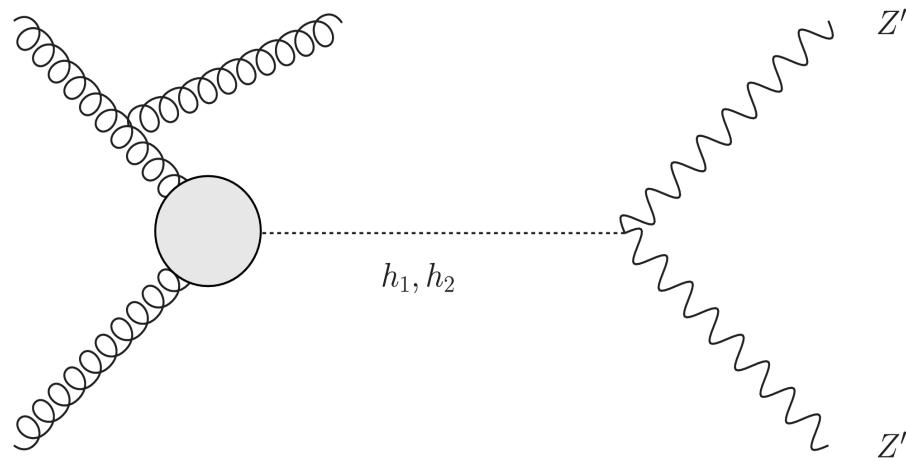
Gauge bosons = DM *or* decay into DM

Higgs potential and cosmology

Degrassi et al.'12

SM stability bound: $m_h >$ 126 GeV at 98% CL
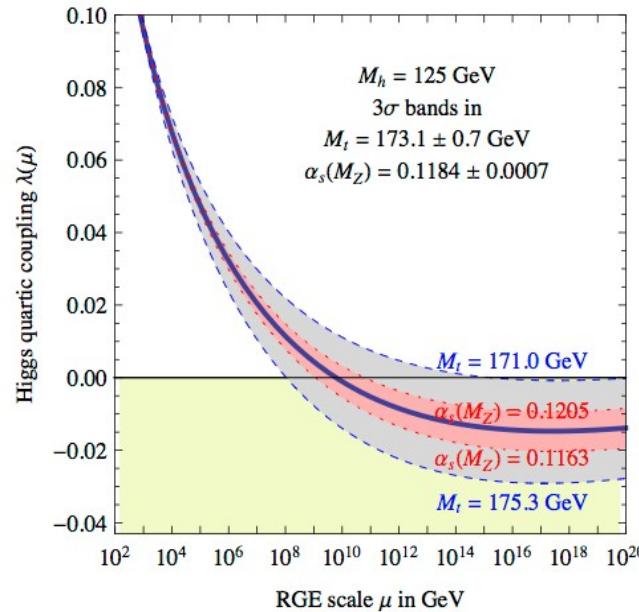
(not settled : Alekhin et al. '12
                Bezrukov et al. '12)

$h \gg \Lambda \sim 10^{10}\,\text{GeV}$ $\Rightarrow$ $V \sim \tfrac{1}{4}\,\lambda(h)\,h^4$, $\lambda(h) < 0$

V

you are here

M_{Pl}

h
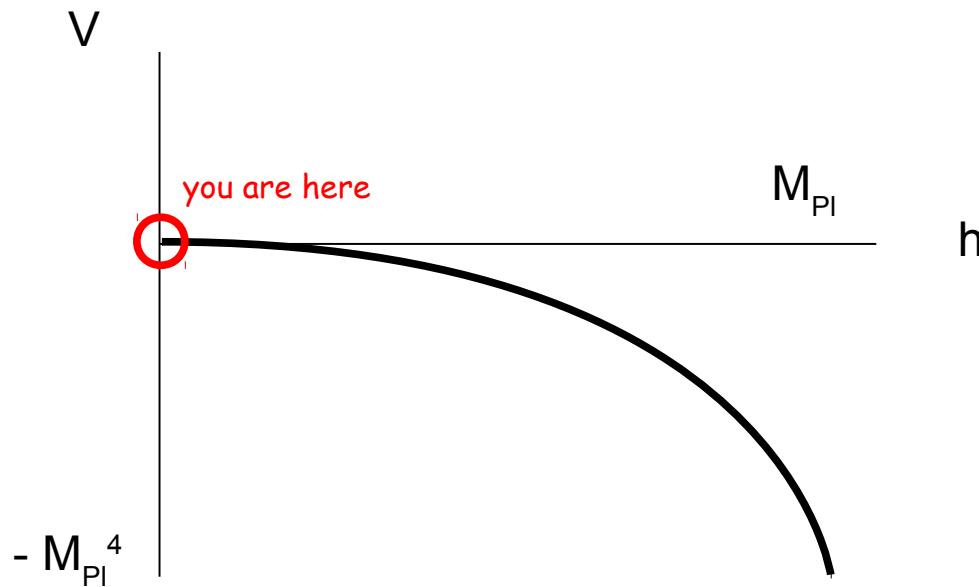
$- M_{Pl}^4$

$\Lambda = 10^{-8}\,M_{Pl}$, barrier $= 10^{-32}\,M_{Pl}^4$

Problems :

- how did the Universe end up at h ~ 0 ?

- why did it stay there during inflation ?

Solutions :

- modify the Higgs potential during inflation

- just modify the Higgs potential

Solution 1:

Higgs-inflaton coupling $\Delta V = \frac{1}{2} \xi\, h^2 \phi^2$ ("Higgs portal" coupling)

$\Delta V + V_{Higgs} > 0$ $\Rightarrow$ $\phi_0 \sim 20\, M_{Pl}$, $\xi \sim 10^{-6}$

Large effective mass term $\Rightarrow$ $h(t) \sim h(0)\, \exp(-\,3/2\, Ht\,)$

Higgs field is driven to zero during inflation !

Higgs/inflaton evolution (in M_{Pl}):
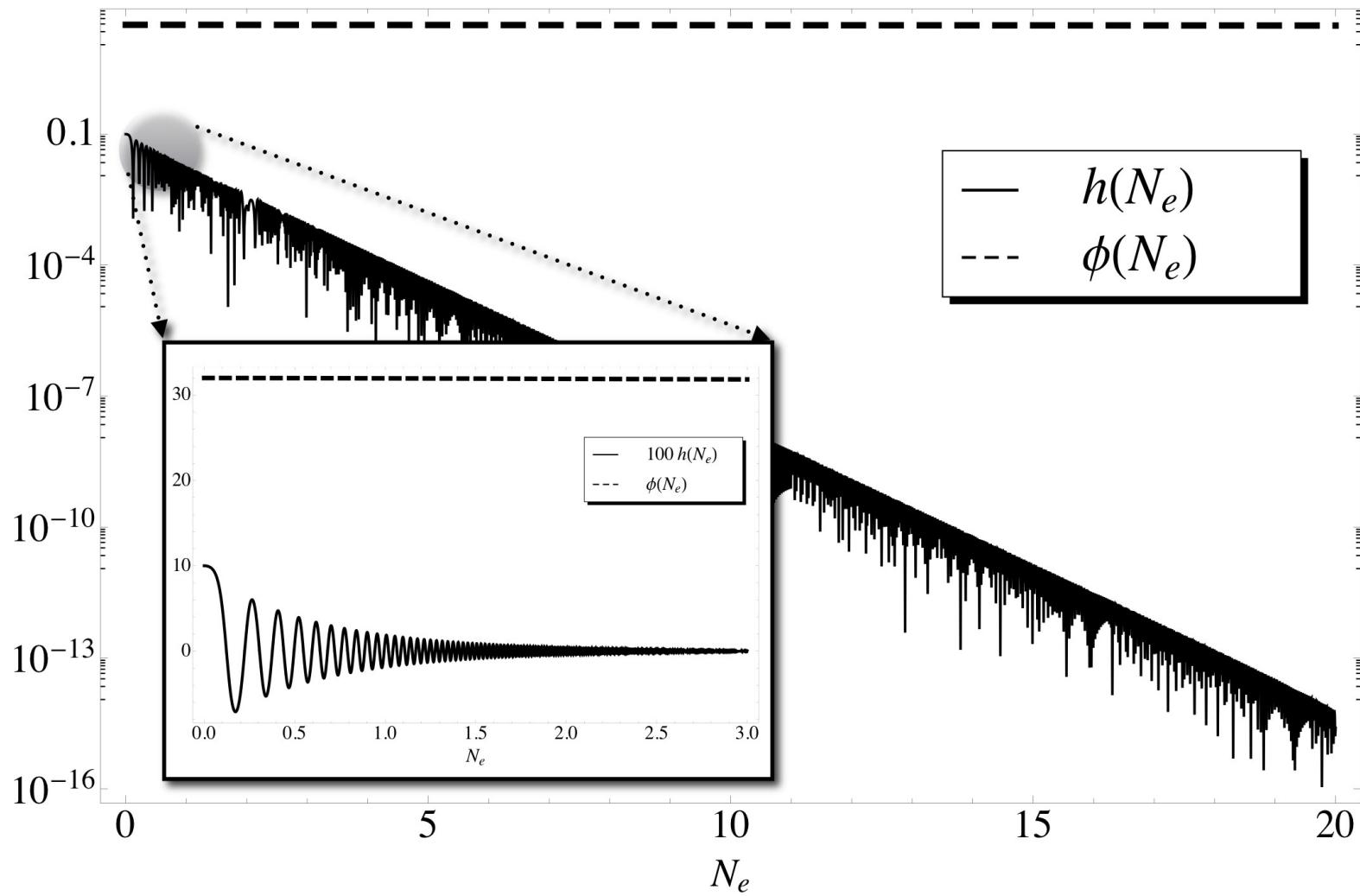
Higgs portal at the LHC

Possible low-energy signatures :

- 2 Higgs-like states

- suppressed couplings

- cascades

H_2 ----- H_1 ..... $\begin{array}{c} b \\ \bar{b} \end{array}$

H_1 ..... $\begin{array}{c} b \\ \bar{b} \end{array}$
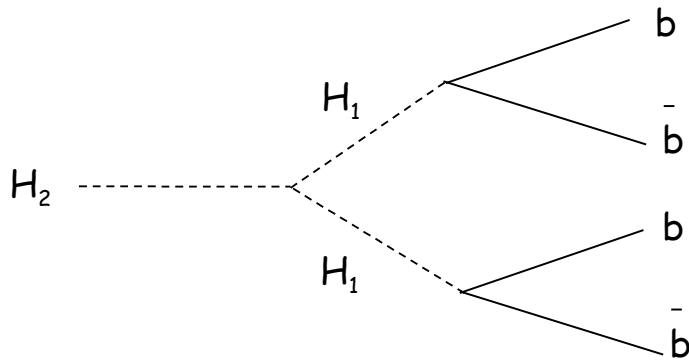
Higgs potential reconstruction :

Englert et al. '11

$$m_1 \, , \; m_2 \, , \; \theta \, , \; H_2 \rightarrow H_1 \, H_1 \quad \Longrightarrow \quad \text{4 parameters of the scalar potential}$$

$H_1 H_1$ production at the pb level:

Falkowski, Gross, OL '05
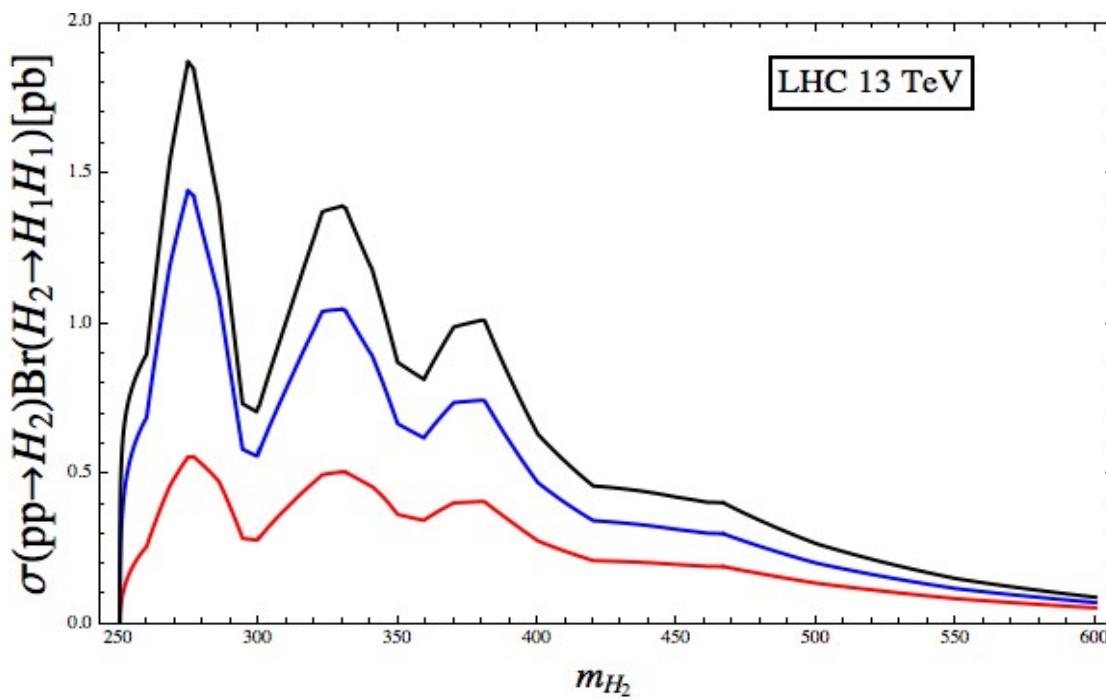
Conclusion

- Higgs sector is special

- key to the hidden sector / DM / inflation

- LHC/direct detection are crucial